Right-Handed New Physics Remains Strangely Beautiful

Daniel T. Larson,[1,2] Hitoshi Murayama,[1,2] and Gilad Perez[1]

[1] *Theoretical Physics Group, Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720*

[2] *Department of Physics, University of California, Berkeley, CA 94720*

(Dated: February 2, 2008)

Current data on CP violation in $B_d \to \eta' K_S$ and $B_d \to \phi K_S$, taken literally, suggest new physics contributions in $b \to s$ transitions. Despite a claim to the contrary, we point out that right-handed operators with a single weak phase can account for both deviations thanks to the two-fold ambiguity in the extraction of the weak phase from the corresponding CP-asymmetry. This observation is welcome since large mixing in the right-handed sector is favored by many GUT models and frameworks which address the flavor puzzle. There are also interesting correlations with the B_s system which provide a way to test this scenario in the near future.

I. INTRODUCTION

Recent years have seen remarkable progress in flavor physics. The dramatic discovery of neutrino oscillations [1], long suspected to be the explanation for the solar neutrino deficit, is the first firm evidence for physics beyond the Standard Model (SM). In the quark sector, T-violation was discovered in the neutral kaon system [2] in agreement with observed indirect CP violation and the CPT theorem. The first example of direct CP violation was also discovered in the neutral kaon system [3]. Finally, both indirect and direct CP violation have been observed for the first time in another system, in the decays $B_d \to J/\psi K_S$ and $B_d \to K\pi$ respectively [4, 5]. The data confirms that the CP violation observed to date originates in the Kobayashi–Maskawa (KM) phase of the quark mixing matrix. It is incredible that all of this has been accomplished in a six-year period! However, the origin of flavor and patterns of masses and mixings still remain elusive.

Interestingly, a deviation from the KM theory has been reported in $B_d^0 \to \phi K_S$ and $B_d^0 \to \eta' K_S$. The time-dependent CP-asymmetries in these modes, denoted $S_{\phi K_S}$ and $S_{\eta' K_S}$ respectively, yield an effective value of $\sin 2\beta = \sin 2\phi_1$ that differs from that in the $J/\psi K_S$ final state.[1] The averages of Belle and BaBar [10] are, according to [11]:

$$S_{\phi K_S} = 0.34 \pm 0.21, \quad S_{\eta' K_S} = 0.41 \pm 0.11, \qquad (1)$$

which should be compared to

$$S_{J/\psi K_S} = 0.726 \pm 0.037. \qquad (2)$$

The discrepancy is 2.7σ for the $\eta' K_S$ mode, and the two modes show values consistent with each other.[2]

The evidence for a new source of CP violation is not yet conclusive. Nonetheless, many new physics models have been shown to contribute significantly to the CP violation in $b \to s$ transitions within the limits from other experimental constraints. For example, the observed large mixing between ν_μ and ν_τ, once grand-unified, can lead to a large mixing between $\tilde{s}_R$ and $\tilde{b}_R$ [12, 13]. There is a growing excitement to see if such new physics scenarios can account for the observed difference between $S_{\phi K_S}$, $S_{\eta' K_S}$ and $S_{J/\psi K_S}$.

The fact that $S_{\phi K_S}$ and $S_{\eta' K_S}$ are similar yields information about the operators responsible for the deviation from $S_{J/\psi K_S}$, and hence a hint as to the underlying new physics. Contributions to B decays proceed through effective operators of two types, $\mathcal{O}_i$ and $\widetilde{\mathcal{O}}_i$ (see *e.g.* [13] for definitions of the relevant operators). The Standard Model contributes only to "left-handed" (LH) operators $\mathcal{O}_i$, while some new physics scenarios, such as mixing between right-handed squarks, only contribute to the "right-handed" (RH) operators $\widetilde{\mathcal{O}}_i$. Several groups [14, 15, 16] have made the observation that $\langle f|\mathcal{O}_i|B\rangle = (-1)^{P_f+1}\langle f|\widetilde{\mathcal{O}}_i|B\rangle$ where P_f is the parity of the final state. Since ϕK is parity odd (a pseudoscalar and vector in a p-wave state) while $\eta' K$ is parity even (two pseudoscalars in an s-wave state), these two final states will be sensitive to different combinations of the $\mathcal{O}_i$ and $\widetilde{\mathcal{O}}_i$ operators.

In [16] it is claimed that the recent measurements of the CP-asymmetries $S_{\phi K_S}$ and $S_{\eta' K_S}$ imply that the additional CP-violating phases appear in the mixing of left-handed squarks and not right-handed squarks. Here we demonstrate that this is not necessarily the case. Because of the two-fold ambiguity in the extraction of the weak phase from $S_{\phi K_S}$ and $S_{\eta' K_S}$, right-handed operators with a single new CP phase can successfully account for the observed discrepancies. The preferred parameter region is more tightly constrained than that for the opposite chirality, but this allows for a more precise study of correlations with other observables such as B_s mixing and $S_{\psi\phi}$. Thus we may be able to test this scenario in the near future.

---

[1] The SM predicts this deviation is at most $\mathcal{O}(0.1)$. For more details see [6, 7, 8, 9].

[2] There is a slight inconsistency in the measurements of $S_{\eta' K_S}$ at BaBar and Belle [10].

II. SIMPLIFIED GENERAL ANALYSIS

We are interested in a scenario in which the new physics contribution is dominated by right-handed operators with a single source of CP violation. In Section V we will comment on the role of strong phases, but for simplicity we shall begin by assuming that all strong phases are negligible. In that case the amplitude for the B-meson decay can be written

$$\mathcal{A}(B^0 \to \phi, \eta') = \mathcal{A}^{\rm SM}_{\phi,\eta'} \left(1 \pm r_{\phi,\eta'} e^{i\sigma_s}\right) \tag{3}$$

where σ_s is the weak phase of the RH operators and

$$r_{\phi,\eta'} \equiv \left| \frac{\mathcal{A}^{\rm NP}_{\phi,\eta'}}{\mathcal{A}^{\rm SM}_{\phi,\eta'}} \right| . \tag{4}$$

It is known that the matrix elements for B decays normalized to the SM contributions are similar for the final states ϕK and $\eta' K$ [14], so as a first approximation we will assume that they are in fact identical. This means

$$r_\phi = r_{\eta'} \equiv r \, . \tag{5}$$

We will use this approximation for our general analysis, but will come back to discuss deviations from this assumption in Section III.

The mixing induced CP asymmetry is given by

$$S_{\phi,\eta'} = {\rm Im} \left(- \frac{\bar{A}_{\phi,\eta'}}{A_{\phi,\eta'}} \frac{V_{td} V^*_{tb}}{V^*_{td} V_{tb}} \frac{V_{cs} V^*_{cd}}{V^*_{cs} V_{cd}} \right) , \tag{6}$$

where the second factor is the $B^0 - \overline{B^0}$ mixing, and the third factor is the $K^0 - \overline{K^0}$ mixing. Using Equation (3) and assuming the SM contribution is purely real we find

$$S_{\phi,\eta'} = \frac{\sin(2\beta) \pm 2r \sin(2\beta + \sigma_s) + r^2 \sin(2\beta + 2\sigma_s)}{1 \pm 2r \cos\sigma_s + r^2} \tag{7}$$

where $V_{td} = |V_{td}|\, e^{-i\beta}$.

It is useful to first consider the two interesting limits of small and large r. For small r we find

$$\lim_{r \to 0} \left(S_{\phi,\eta'}\right) \approx \sin(2\beta) \pm 2r \cos 2\beta \sin\sigma_s \, . \tag{8}$$

Since the measured $S_{\phi K_S}$ and $S_{\eta' K_S}$ are both smaller than $\sin 2\beta$, it is clear that a single RH operator cannot account for the data when r is small. On the other hand, when r is large we find

$$\lim_{r \to \infty} \left(S_{\phi,\eta'}\right) \approx \sin(2\beta + 2\sigma_s) \mp \frac{2}{r} \cos(2\beta + 2\sigma_s) \sin\sigma_s \, , \tag{9}$$

which naturally leads to deviations for $S_{\phi K_S}$ and $S_{\eta' K_S}$ in the same direction. In reality we expect that r will lie somewhere between these two extremes. But studying these limits shows that RH operators require sizeable new physics contributions ($r \gtrsim \mathcal{O}(1)$) to account for the data. This contrasts with the case of LH operators where new physics contributions can be as small as $r \sim 0.2$.

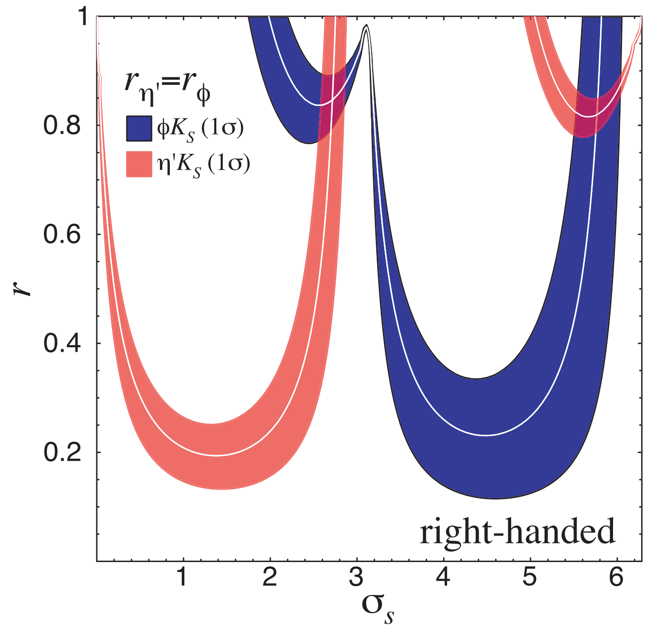

FIG. 1: Central value and 1-sigma contours of $S_{\phi K_S}$ (blue) and $S_{\eta' K_S}$ (pink) for a RH new physics contribution as a function of σ_s and $r = r_\phi = r_{\eta'}$.

We can analyze the situation more precisely by plotting $S_{\phi K_S}$ and $S_{\eta' K_S}$ as functions of r and σ_s. Figure 1 shows the central value and one-sigma contours of $S_{\phi K_S}$ and $S_{\eta' K_S}$. The bands overlap in the two regions around $(\sigma_s, r) \sim (2.7, 0.8)$ and $(5.7, 0.8)$. This implies that a single RH operator *can* account for the experimental results, despite the claim in [16]. In addition, since there are only two discrete regions that are consistent with the data, we can hope to find strong correlations with other observables.

For comparison, in Figure 2 we show the same contours but this time assuming the new physics contribution comes from LH operators. As expected, since there is no longer a relative sign difference between the new physics contributions to $S_{\phi K_S}$ and $S_{\eta' K_S}$, the overlap regions are much larger. Thus a wider range of parameters is consistent with the data, but that also means less information can be extracted. The difference between Figures 1 and 2 is what led to the the conclusion in [16] that new physics contributions to LH operators are favored, but we clearly see that contributions from RH operators are not excluded yet, especially if one considers the 2σ allowed regions, which are shown in Figure 3.

These remaining allowed regions for RH operators are important because flavor violation from new degrees of freedom is aligned with that of the SM in many simple flavor models such as Abelian [17] and non-Abelian [18] horizontal models, split fermion models [19] and RS1 models [20]. This implies the following relation between the quark masses and left and right diagonalization

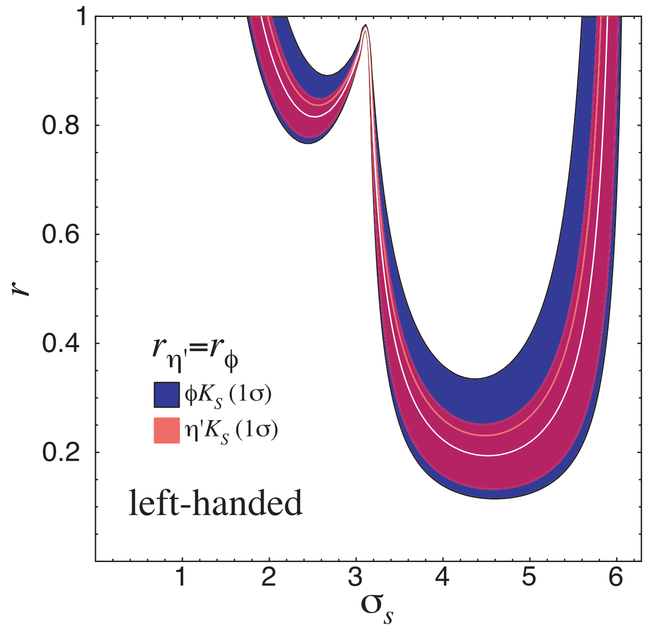

FIG. 2: Central value and 1-sigma contours of $S_{\phi K_S}$ (blue) and $S_{\eta' K_S}$ (pink) for a LH new physics contribution as a function of σ_s and $r = r_\phi = r_{\eta'}$.

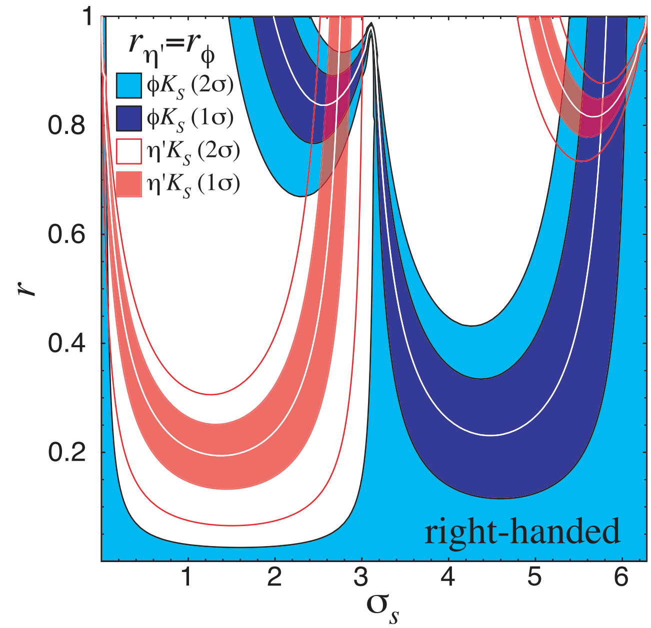

FIG. 3: Central value, 1- and 2-sigma contours of $S_{\phi K_S}$ (blue) and $S_{\eta' K_S}$ (pink) for a RH new physics contribution as a function of σ_s and $r = r_\phi = r_{\eta'}$.

matrices $D_{R,L}$ of the down type Yukawa matrix:

$$m_s/m_b \sim (D_L)_{23}\,(D_R)_{23} \lesssim (V_{\rm CKM})_{23}\,(D_R)_{23}\ , \qquad (10)$$

which implies

$$(D_R)_{23} = \mathcal{O}(1)\,. \qquad (11)$$

Thus we generically expect new physics to induce RH operators which are not suppressed by V_{cb} and therefore might yield the dominant contribution. Also, constraints from some measurements such as $b \to s\gamma$ are weaker for RH operators because the LH contributions add coherently to the SM whereas RH contributions add incoherently.

The reason our conclusion differs from the one presented in [16] is that we rely on the discrete ambiguities in the sine function. In the presence of new physics contributions we can parameterize the CP asymmetries as

$$S_{\phi,\eta'} = \sin(2\beta + \Sigma_{\phi,\eta'}) \qquad (12)$$

where

$$\Sigma_{\phi,\eta'} = \arg\left(\frac{1 \pm r e^{i\sigma_s}}{1 \pm r e^{-i\sigma_s}}\right) \qquad (13)$$

is the phase coming from the decay amplitude. There are two solutions to Equation (12), namely

$$\begin{aligned} \Sigma_{\phi,\eta'} &= \arcsin\left(S_{\phi,\eta'}\right) - 2\beta & (14)\\ &\sim \frac{\pi}{8} - \frac{\pi}{4} = -\frac{\pi}{8} \sim -0.39 & (15)\end{aligned}$$

and

$$\begin{aligned} \Sigma_{\phi,\eta'} &= \pi - 2\beta - \arcsin\left(S_{\phi,\eta'}\right) & (16)\\ &\sim \pi - \frac{\pi}{4} - \frac{\pi}{8} = \frac{5\pi}{8} \sim 1.96\,, & (17)\end{aligned}$$

where in the second line of each solution we have used the rough approximation $S_{\phi K_S} \sim S_{\eta' K_S} \sim \sin(\pi/8)$ and $2\beta \sim \pi/4$. As argued above, for a RH operator to give a contribution such that $\Sigma_\phi \sim \Sigma_{\eta'}$ we would need $r \gg 1$, which would likely already have been observed. Thus we are led to consider a mixed scenario, which means we expect solutions centered around $(\Sigma_\phi, \Sigma_{\eta'}) = (-\pi/8, 5\pi/8)$ or $(5\pi/8, -\pi/8)$. This agrees with the numbers one extracts from the regions of overlap in Fig. 1.

III. MORE REALISTIC ANALYSIS

In the previous section we have analyzed the situation where the size of the new physics amplitude relative to the SM is the same for both the ϕK and $\eta' K$ final states. This assumption can be checked using a specific hadronic model. Within the framework of naive factorization we found that $r_\phi/r'_\eta \sim \mathcal{O}(1)$ for the relevant operators. For instance the chromomagnetic operator, which often gives the dominant contribution, yields $r_\phi/r'_\eta \simeq 0.9$, demonstrating that this assumption is reasonable.

We can relax the assumption in Equation (5) but still assume that the new physics is governed by a single source of CP violation. In this situation we expect order

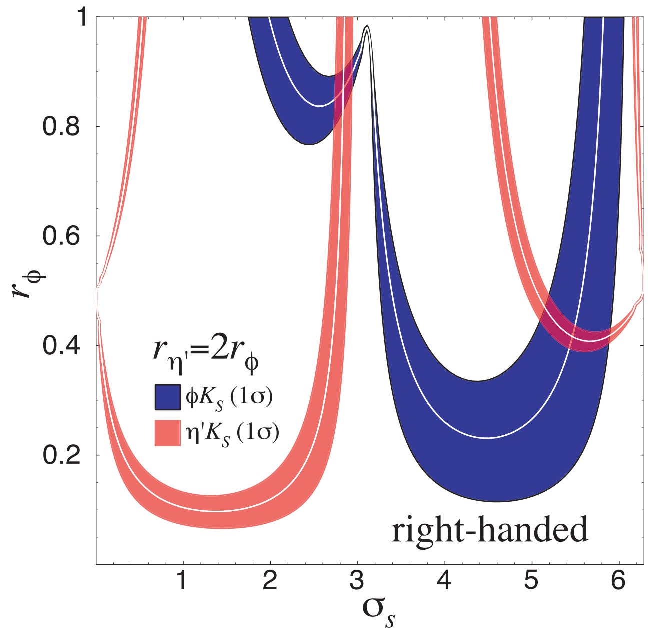

FIG. 4: Central value and 1-sigma contours of $S_{\phi K_S}$ (blue) and $S_{\eta' K_S}$ (pink) for a RH new physics contribution as a function of σ_s and r_ϕ, with $r_{\eta'} = 2r_\phi$.

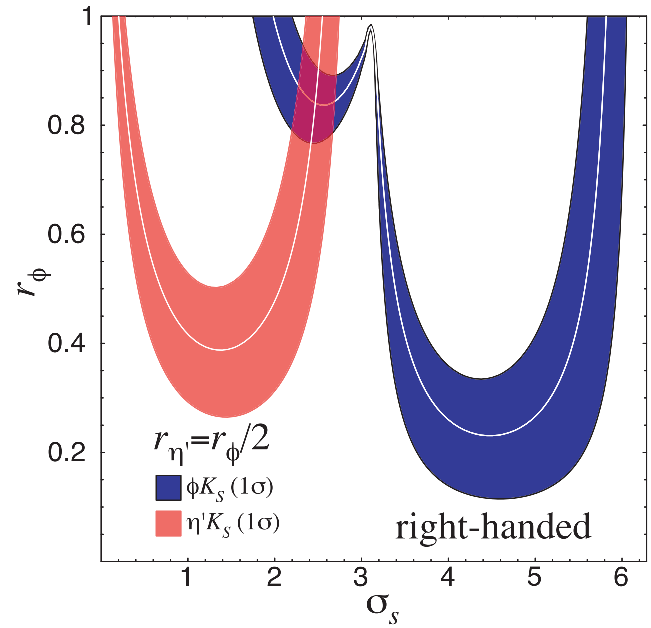

FIG. 5: Central value and 1-sigma contours of $S_{\phi K_S}$ (blue) and $S_{\eta' K_S}$ (pink) for a RH new physics contribution as a function of σ_s and r_ϕ, with $r_{\eta'} = r_\phi/2$.

one variations between r_ϕ and $r_{\eta'}$.[3] To demonstrate the effect of variations of r, we plot contours of $S_{\phi K_S}$ and $S_{\eta' K_S}$ as a function of σ_s and r_ϕ with $r_{\eta'} = 2r_\phi$ (Figure 4) and $r_{\eta'} = r_\phi/2$ (Figure 5). These figures show that, despite the shift in the contours, regions of overlap still remain where RH operators can account for the deviations in $S_{\phi K_S}$ and $S_{\eta' K_S}$ from $S_{J/\psi K_S}$, even when $r_\phi \neq r_{\eta'}$. In fact, for LH operators the overlap of the contours starts to separate when $r_\phi \neq r_{\eta'}$ as shown in Figures 6 and 7. This demonstrates that the ease with which the LH operators can fit the data is dependent on the similarity between the relative size of new physics contributions to ϕK and $\eta' K$ final states.

In reality there are further complications. The presence of strong phases that differ for ϕK and $\eta' K$ final states will generally lead to different dependence on σ_s, reducing the strong correlations between the two modes. Also, the absorptive part of the $c\bar{c}$ loop needs to be taken into consideration, which introduces another strong phase. The situation is less clear-cut if there are multiple new CP phases in the new physics sector. Finally, the uncertainties in hadronic matrix elements will always add further complication. Eventually all of these subtleties must be addressed, but at this early stage of the analysis it is important to study the general features and see how far that will take us.

IV. CORRELATIONS WITH THE $B_s - \overline{B}_s$ SYSTEM

Let us continue with our assumption that new physics contributions are dominated by a single source of CP violation which appears only in the RH operators. This implies that we can parameterize the contribution to the $B_s - \overline{B}_s$ transition amplitude, M_{12}^s, as

$$M_{12}^s = M_{12}^{s\,\mathrm{SM}} \left(1 + h_s e^{2i\sigma_s}\right) , \qquad (18)$$

where h_s is the ratio of new physics to SM contributions, and σ_s is the same phase that appears in Equation (3) for the B_d decays. In principle h_s could be quite large, though we expect it to be order one in most models. Note also that the sign of h_s is model dependent, so in our analysis below we consider both positive and negative values. With this parameterization the mass difference between B_s^0 and $\overline{B^0}_s$ is given by

$$\Delta m_s = \Delta m_s^{\mathrm{SM}} \left|1 + h_s e^{2i\sigma_s}\right| . \qquad (19)$$

So far experiments have only yielded a lower bound on the value of the mass difference, $\Delta m_s^{\mathrm{exp}} > 14.5\ \mathrm{ps}^{-1}$ [21]. The SM prediction of Δm_s has significant hadronic uncertainties, but a much cleaner prediction is available for the ratio $\Delta m_s/\Delta m_d$. Since the new physics contribution to $b \to d$ transitions is very tightly constrained by current measurements [11], we will assume that $\Delta m_d \sim$

[3] Applying the analysis presented in [13] to estimate the hadronic matrix elements, we have checked that for a specific model with RH squark mixing between the 2nd and 3rd generations r_ϕ and $r_{\eta'}$ are within a factor of 2 over most of the parameter space.

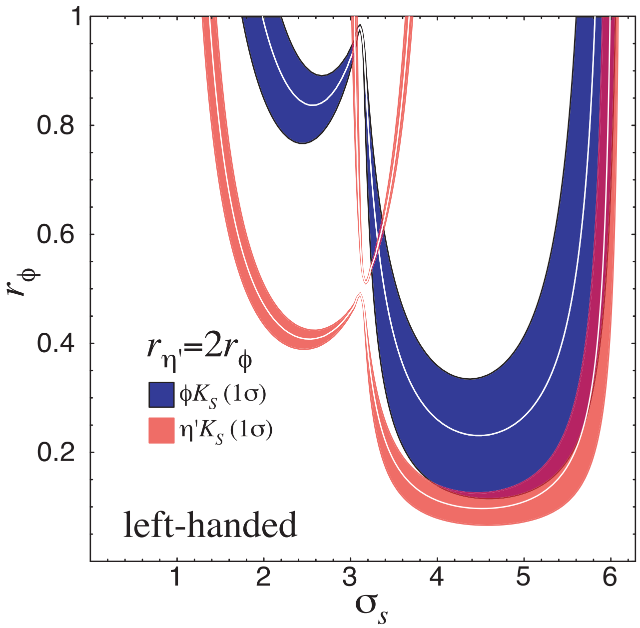

FIG. 6: Central value and 1-sigma contours of $S_{\phi K_S}$ (blue) and $S_{\eta' K_S}$ (pink) for a LH new physics contribution as a function of σ_s and r_ϕ, with $r_{\eta'} = 2r_\phi$.

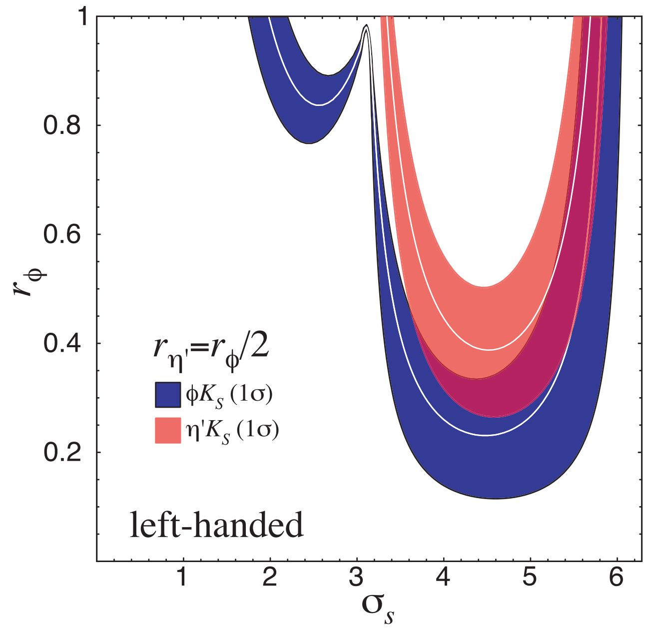

FIG. 7: Central value and 1-sigma contours of $S_{\phi K_S}$ (blue) and $S_{\eta' K_S}$ (red) for a LH new physics contribution as a function of σ_s and r_ϕ, where $r_{\eta'} = r_\phi/2$.

$\Delta m_d^{\rm exp}$. Consequently we can use the state of the art analysis [22] and Equation (19) to find the following relation between the predicted ratio for $\Delta m_s^{\rm SM}/\Delta m_d^{\rm SM}$ and the experimental lower bound on $\Delta m_s^{\rm exp}/\Delta m_d^{\rm exp}$

$$\begin{aligned}\left|1+h_s e^{2i\sigma_s}\right| &= \frac{\Delta m_d^{\rm SM}}{\Delta m_s^{\rm SM}}\frac{\Delta m_s^{\rm exp}}{\Delta m_d^{\rm exp}} = \frac{m_{B_d}}{m_{B_s}}\frac{1}{\xi^2}\frac{|V_{td}|^2}{|V_{ts}|^2} \\ &\gtrsim 0.8\,, \end{aligned} \tag{20}$$

with a 20% uncertainty coming from the CKM factors. Here $\xi = f_{B_s}/f_{B_d}\sqrt{B_{B_s}/B_{B_d}} \sim 1.21 \pm 0.06$ [22] is related to the ratio between the bag parameters and $m_{B_d}/m_{B_s} \approx 0.98$. Equation (20) provides a constraint on the allowed values of h_s and σ_s. The constraint is, at present, rather weak and corresponds to several oval excluded regions shown in Figure 8. Examining the regions of intersection for the 1-sigma contours in Figure 1, we find the following range for σ_s preferred by $S_{\phi K_S}$ and $S_{\eta' K_S}$:

$$\sigma_s = 2.5 - 2.9 \;\; \text{or} \;\; 5.4 - 6.1\,. \tag{21}$$

This corresponds to the two vertical strips shown in Figure 8. At present the regions excluded by the lower bound on Δm_s partially intersect with the regions preferred by $S_{\phi K_S}$ and $S_{\eta' K_S}$ only for negative values of h_s. However, in the near future measurements at the Tevatron, LHC-b, and BTev will either measure Δm_s or significantly raise the lower bound, so the above constraint will play an important role in discriminating between new physics frameworks.

The requirements on σ_s from $S_{\phi K_S}$ and $S_{\eta' K_S}$ are correlated with the prediction for $S_{\psi\phi}$, the CP asymmetry in $B_s \to \psi\phi$. Within the Standard Model, $S_{\psi\phi} \lesssim \lambda^2$, so any CP-asymmetry will only arise from the new phase in the contribution to B_s mixing shown in Equation (18). Thus we find

$$\begin{aligned} S_{\psi\phi} &= \sin\left[\arg\left(1+h_s e^{2i\sigma_s}\right)\right] \\ &= \frac{h_s \sin 2\sigma_s}{\sqrt{(1+h_s\cos 2\sigma_s)^2 + (h_s \sin 2\sigma_s)^2}}\,. \end{aligned} \tag{22}$$

Figure 9 shows the allowed values for $S_{\psi\phi}$ as a function of h_s when σ_s is in the range specified by Equation (21). In addition, the regions excluded by the lower bound on Δm_s are also shown. Already we see some very non-trivial correlations between measurements of $S_{\phi K_S}$, $S_{\eta' K_S}$ and $S_{\psi\phi}$ that will only get stronger as the data improve.

V. DISCUSSION

So far we have assumed that all strong phases are negligible. In the framework of naive factorization this is expected. However, there is now some evidence to the contrary due to the observation of direct CP-violation in the decay $\overline{B^0} \to K^+\pi^-$ [5]. The presence of large strong phases, which should generically be different for ϕK and $\eta' K$ final states, complicate the analysis and make it more sensitive to the framework used to estimate the hadronic matrix elements.

When the new physics contribution is large one would generically expect to measure direct CP-violation. Currently the experimental limits are $|C_{\phi K_S}| < 0.2$ and

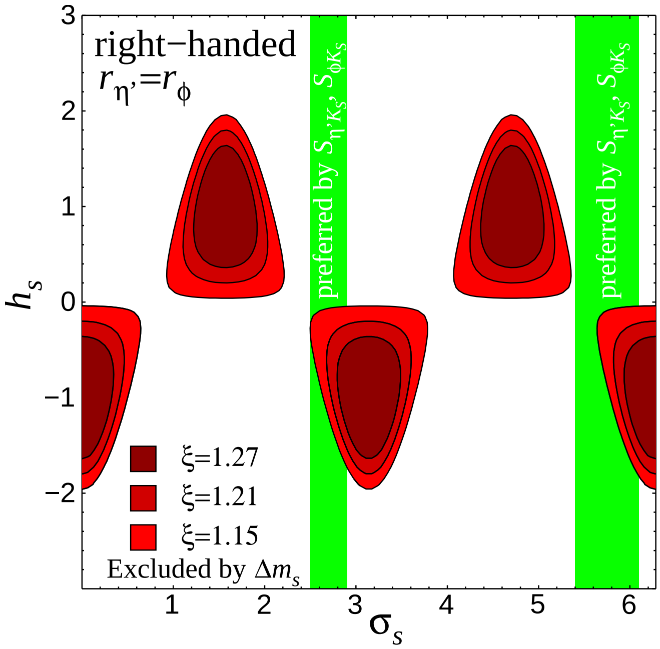

FIG. 8: The $\sigma_s - h_s$ plane showing the regions excluded by the lower bound on Δm_s (red ovals) and also the regions preferred by $S_{\phi K_S}$ and $S_{\eta' K_S}$ as given in Equation (21) (green bands).

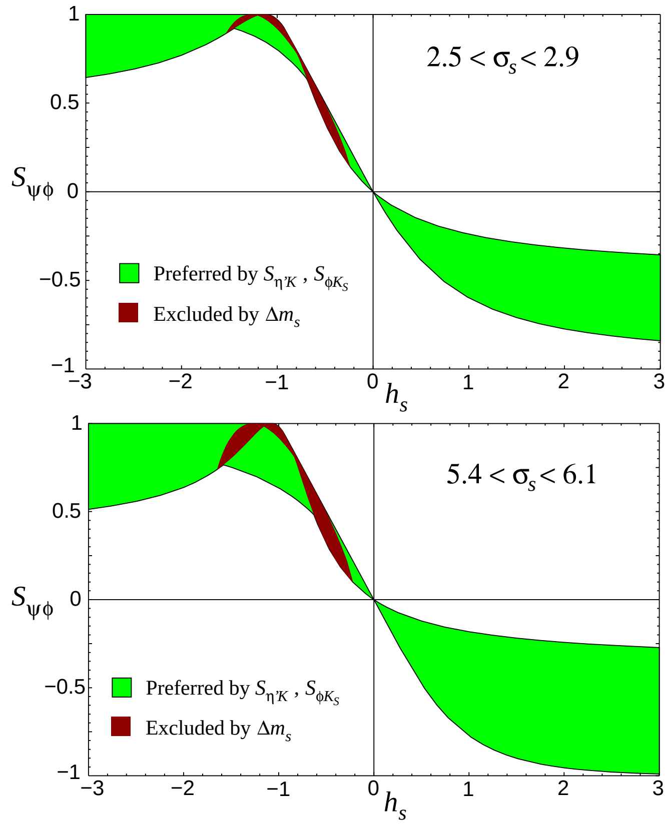

FIG. 9: Allowed regions for $S_{\psi\phi}$ as a function of h_s (green) and the regions excluded by the lower bound on Δm_s (red). The upper plot corresponds to $\sigma_s \in [2.5, 2.9]$ while the lower plot corresponds to $\sigma_s \in [5.4, 6.1]$. The ranges for σ_s are those compatible with the measured values of $S_{\phi K_S}$ and $S_{\eta' K_S}$.

$|C_{\eta' K_S}| < 0.1$ [11]. Using isospin symmetry one finds much stronger constraints from measurements of the CP asymmetries, $A^{\rm CP}_{\phi,\eta' K^\pm}$, in the charged modes $B^\pm \to \phi K^\pm$, $\eta' K^\pm$.[4] Using the world averages one finds [21]

$$A^{\rm CP}_{\phi K^\pm} = 0.04 \pm 0.05\,, \quad A^{\rm CP}_{\eta' K^\pm} = 0.02 \pm 0.04\,. \tag{23}$$

Nevertheless, there is significant uncertainty in this constraint, especially if $r_\phi \neq r_{\eta'}$. In the future, if the bounds on the direct CP-asymmetries improve they will limit the size of the strong phases compatible with RH new physics. This is in contrast to the case of LH contributions where r generically need not be as big, reducing the sensitivity to measurements of direct CP-violation.

Depending on the specific operators involved, there are many other constraints and correlations that can be studied. For instance, if the chromomagnetic dipole operator is the dominant source of new physics, there will also likely be a large contribution to the electromagnetic dipole operator responsible for the decay $b \to s\gamma$. However, in this case it has been shown that there can be a significant contribution to $S_{\phi K_S}$ without violating the $b \to s\gamma$ constraint [13, 23, 24]. Another stringent constraint comes from the limit on the chromoelectric dipole moment of the strange quark derived from experimental limits on the EDMs of the neutron and ^{199}Hg [25, 26, 27].

[4] Assuming that there is no exact cancellation between rescattering amplitudes [9].

Other constraints like $b \to s\ell^+\ell^-$ are starting to become important as well. Of course, for any specific framework all available constraints need to be studied, but such model dependent issues are beyond the scope of this work.

VI. CONCLUSIONS

We have studied a generic framework in which new physics contributions only induce right-handed operators with a single CP violating phase. This assumption leads to the following interesting consequences:

(i) Despite the opposite parity of the ϕK and $\eta' K$ final states, RH operators can still account for the experimental data thanks to the two-fold ambiguity in $S_{\phi,\eta'} = \sin(2\beta + \Sigma_{\phi,\eta'})$.

(ii) The favored parameter region is more tightly constrained for RH operators than for LH operators, and sizable new physics contributions comparable in size to the SM are required.

(iii) The ease with which LH operators can accommo-

date $S_{\phi K_S}$ and $S_{\eta' K_S}$ is diminished when there are significant differences between relative size of new physics contributions to the two modes.

(iv) Fitting the data with RH operators efficiently constrains the new physics phase. Thus we find that the CP-asymmetries in $B \to \phi, \eta' K_S$ are correlated with observables from the $B_s - \overline{B}_s$ system such as Δm_s and the CP asymmetry in $B_s \to \psi\phi$.

Work is underway to test the viability of this scenario in the framework of a specific model of RH squark mixing, where the constraints such as $b \to s\gamma$, $b \to sl^+l^-$ and the EDM of ^{199}Hg can also be imposed. We conclude that it is too early to rule out the contributions from right-handed operators to the CP-asymmetries in $b \to s$ transitions.

Acknowledgments

GP thanks K. Agashe, Y. Grossman, M. Neubert and M. Papucci for helpful discussions. This work was supported in part by the DOE under contracts DE-AC03-76SF00098 and in part by NSF grant PHY-0098840.

---

[1] Y. Fukuda *et al.* [Super-Kamiokande Collaboration], Phys. Rev. Lett. **81**, 1562 (1998) [arXiv:hep-ex/9807003]; Q. R. Ahmad *et al.* [SNO Collaboration], Phys. Rev. Lett. **89**, 011301 (2002) [arXiv:nucl-ex/0204008]; K. Eguchi *et al.* [KamLAND Collaboration], Phys. Rev. Lett. **90**, 021802 (2003) [arXiv:hep-ex/0212021].

[2] A. Angelopoulos *et al.* [CPLEAR Collaboration], Phys. Lett. B **444**, 43 (1998).

[3] A. Alavi-Harati *et al.* [KTeV Collaboration], Phys. Rev. D **67**, 012005 (2003) [arXiv:hep-ex/0208007]; J. R. Batley *et al.* [NA48 Collaboration], Phys. Lett. B **544**, 97 (2002) [arXiv:hep-ex/0208009]; G. D. Barr *et al.* [NA31 Collaboration], Phys. Lett. B **317**, 233 (1993); L. K. Gibbons *et al.*, Phys. Rev. Lett. **70**, 1203 (1993).

[4] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **87**, 091801 (2001) [arXiv:hep-ex/0107013]; K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **87**, 091802 (2001) [arXiv:hep-ex/0107061].

[5] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. Lett. **93**, 131801 (2004) [arXiv:hep-ex/0407057]; Y. Chao *et al.* [Belle Collaboration], arXiv:hep-ex/0408100.

[6] Y. Grossman and M. P. Worah, Phys. Lett. B **395**, 241 (1997) [arXiv:hep-ph/9612269].

[7] D. London and A. Soni, Phys. Lett. B **407**, 61 (1997) [arXiv:hep-ph/9704277].

[8] M. Beneke and M. Neubert, Nucl. Phys. B **675**, 333 (2003) [arXiv:hep-ph/0308039].

[9] Y. Grossman, Z. Ligeti, Y. Nir and H. Quinn, Phys. Rev. D **68**, 015004 (2003) [arXiv:hep-ph/0303171].

[10] K. Abe *et al.* [BELLE Collaboration], arXiv:hep-ex/0409049; B. Aubert *et al.* [BABAR Collaboration], arXiv:hep-ex/0408072; B. Aubert *et al.* [BABAR Collaboration], arXiv:hep-ex/0408090.

[11] Z. Ligeti, arXiv:hep-ph/0408267.

[12] D. Chang, A. Masiero and H. Murayama, Phys. Rev. D **67**, 075013 (2003) [arXiv:hep-ph/0205111]; M. Ciuchini, A. Masiero, L. Silvestrini, S. K. Vempati and O. Vives, Phys. Rev. Lett. **92**, 071801 (2004) [arXiv:hep-ph/0307191]; S. Jager and U. Nierste, arXiv:hep-ph/0410360.

[13] R. Harnik, D. T. Larson, H. Murayama and A. Pierce, Phys. Rev. D **69**, 094024 (2004) [arXiv:hep-ph/0212180].

[14] S. Khalil and E. Kou, Phys. Rev. Lett. **91**, 241602 (2003) [arXiv:hep-ph/0303214].

[15] A. L. Kagan, arXiv:hep-ph/0407076.

[16] M. Endo, S. Mishima and M. Yamaguchi, arXiv:hep-ph/0409245.

[17] Y. Nir and G. Raz, Phys. Rev. D **66**, 035007 (2002) [arXiv:hep-ph/0206064]; Y. Nir and N. Seiberg, Phys. Lett. B **309**, 337 (1993) [arXiv:hep-ph/9304307]; M. Leurer, Y. Nir and N. Seiberg, Nucl. Phys. B **420**, 468 (1994) [arXiv:hep-ph/9310320].

[18] R. G. Roberts, A. Romanino, G. G. Ross and L. Velasco-Sevilla, Nucl. Phys. B **615**, 358 (2001) [arXiv:hep-ph/0104088]; G. G. Ross, L. Velasco-Sevilla and O. Vives, Nucl. Phys. B **692**, 50 (2004) [arXiv:hep-ph/0401064].

[19] N. Arkani-Hamed and M. Schmaltz, Phys. Rev. D **61**, 033005 (2000) [arXiv:hep-ph/9903417]; E. A. Mirabelli and M. Schmaltz, Phys. Rev. D **61**, 113011 (2000) [arXiv:hep-ph/9912265]; D. E. Kaplan and T. M. P. Tait, JHEP **0111**, 051 (2001) [arXiv:hep-ph/0110126]; Y. Grossman and G. Perez, Phys. Rev. D **67**, 015011 (2003) [arXiv:hep-ph/0210053]; G. C. Branco, A. de Gouvea and M. N. Rebelo, Phys. Lett. B **506**, 115 (2001) [arXiv:hep-ph/0012289].

[20] S. J. Huber and Q. Shafi, Phys. Lett. B **498**, 256 (2001) [arXiv:hep-ph/0010195]; G. Burdman, Phys. Lett. B **590**, 86 (2004) [arXiv:hep-ph/0310144]; K. Agashe, G. Perez and A. Soni, arXiv:hep-ph/0408134, to appear in Phys. Rev. D; arXiv:hep-ph/0406101, to appear in Phys. Rev. Let.

[21] Heavy Flavor Averaging Group, http://www.slac.stanford.edu/xorg/hfag/ .

[22] J. Charles *et al.* [CKMfitter Group Collaboration], arXiv:hep-ph/0406184.

[23] G. L. Kane, P. Ko, H. b. Wang, C. Kolda, J. H. Park and L. T. Wang, Phys. Rev. D **70**, 035015 (2004) [arXiv:hep-ph/0212092].

[24] M. Ciuchini, E. Franco, A. Masiero and L. Silvestrini, Phys. Rev. D **67**, 075016 (2003) [Erratum-ibid. D **68**, 079901 (2003)] [arXiv:hep-ph/0212397].

[25] J. Hisano and Y. Shimizu, arXiv:hep-ph/0406091.

[26] J. Hisano and Y. Shimizu, Phys. Lett. B **581**, 224 (2004) [arXiv:hep-ph/0308255].

[27] G. L. Kane, H. b. Wang, L. T. Wang and T. T. Wang, arXiv:hep-ph/0407351.